

Wave Basics

Waves transfer energy from one place to another without transferring any matter (stuff).

Waves Transfer Energy in the Direction they are Travelling

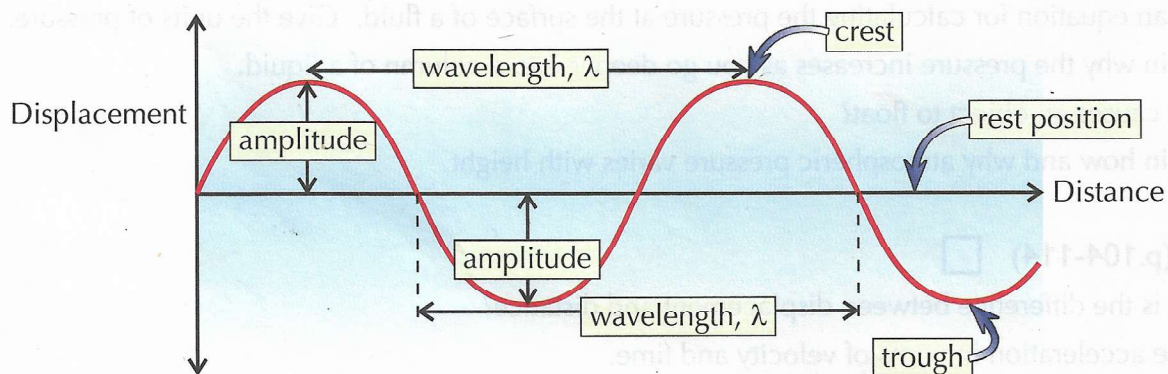
When waves travel through a medium, the particles of the medium oscillate and transfer energy between each other. BUT overall, the particles stay in the same place — only energy is transferred.

For example, if you drop a twig into a calm pool of water, ripples form on the water's surface. The ripples don't carry the water (or the twig) away with them though. Similarly, if you strum a guitar string and create sound waves, the sound waves don't carry the air away from the guitar and create a vacuum.

Waves have Amplitude, Wavelength and Frequency

- 1) The amplitude of a wave is the maximum displacement of a point on the wave from its undisturbed position.

- 2) The wavelength is the distance between the same point on two adjacent waves (e.g. between the trough of one wave and the trough of the wave next to it).



- 3) Frequency is the number of complete waves passing a certain point per second. Frequency is measured in hertz (Hz). 1 Hz is 1 wave per second.

The period of a wave is the amount of time it takes for a full cycle of the wave to pass a point. You can find it from the frequency of the wave using the formula:

$$\text{Period (s)} \quad T = \frac{1}{f} \quad \text{Frequency (Hz)}$$



The only thing a wave transfers is energy...

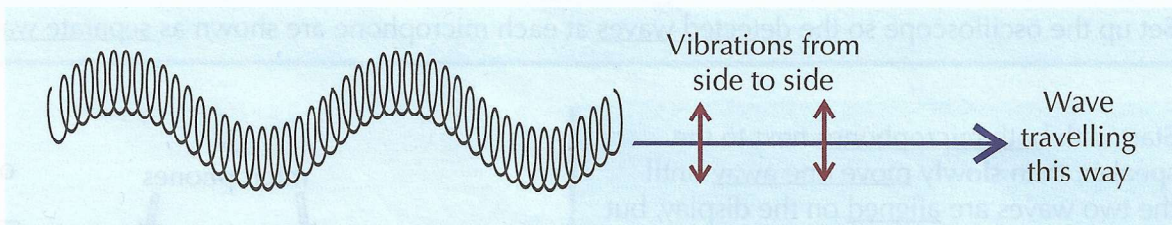
It's really important that you understand this stuff really well, or the rest of this topic will simply be a blur. Make sure you can sketch the wave diagram above and can label all the features from memory. Then check you know all the definitions and the equation linking period and frequency.

Transverse and Longitudinal Waves

All waves are either transverse or longitudinal. Read on to find out more...

Transverse Waves Have Perpendicular Vibrations

In transverse waves, the oscillations (vibrations) are perpendicular (at 90°) to the direction of energy transfer. A spring wiggled from side to side gives a transverse wave:



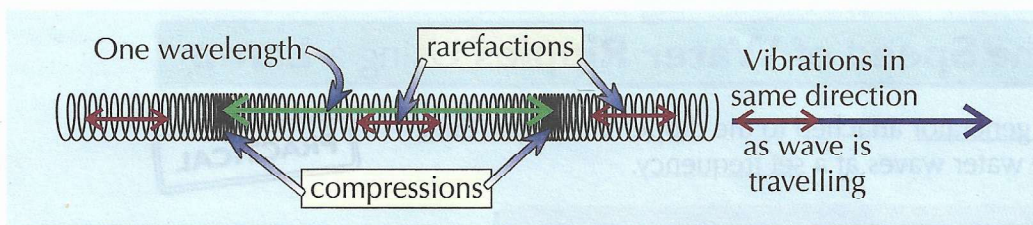
Most waves are transverse, including:

- 1) All electromagnetic waves, e.g. light (page 136).
- 2) Ripples and waves in water (page 128).
- 3) A wave on a string (page 129).

Longitudinal Waves Have Parallel Vibrations

In longitudinal waves, the oscillations are parallel to the direction of energy transfer. If you push the end of a spring, you get a longitudinal wave.

Water waves, shock waves and waves in springs and ropes are all examples of mechanical waves.



Other examples of longitudinal waves are:

- 1) Sound waves in air, ultrasound.
- 2) Shock waves, e.g. some seismic waves (see page 155).

Wave Speed = Frequency $\times$ Wavelength

The wave speed is the speed at which energy is being transferred (or the speed the wave is moving at). The wave equation applies to all waves:

$$\text{Wave speed (m/s)} \quad \boxed{v = f\lambda} \quad \begin{array}{l} \text{Wavelength (m)} \\ \text{Frequency (Hz)} \end{array}$$

EXAMPLE:

A radio wave has a frequency of 12.0×10^6 Hz. Find its wavelength.
(The speed of radio waves in air is 3.0×10^8 m/s.)

- 1) To find λ , you need to rearrange the equation $v = f\lambda$.
- 2) Substitute in the values for v and f to calculate λ .

$$\begin{aligned} \lambda &= v \div f \\ &= (3.0 \times 10^8) \div (12.0 \times 10^6) = 25 \text{ m} \end{aligned}$$

Experiments with Waves

Measuring the speed of waves isn't that simple. It calls for crafty methods...

Use an Oscilloscope to Measure the Speed of Sound

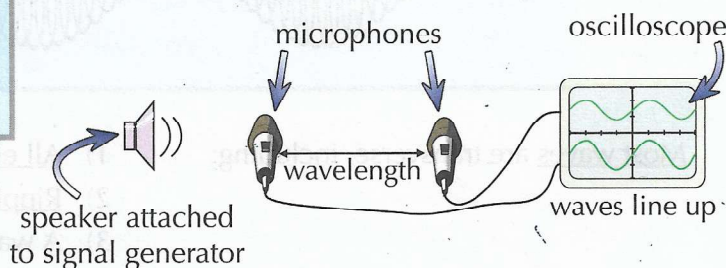
By attaching a signal generator to a speaker you can generate sounds with a specific frequency. You can use two microphones and an oscilloscope to find the wavelength of the sound waves generated.

1) Set up the oscilloscope so the detected waves at each microphone are shown as separate waves.

2) Start with both microphones next to the speaker, then slowly move one away until the two waves are aligned on the display, but have moved exactly one wavelength apart.

3) Measure the distance between the microphones to find one wavelength (λ).

4) You can then use the formula $v = f\lambda$ (see last page) to find the speed (v) of the sound waves passing through the air — the frequency (f) is whatever you set the signal generator to (around 1 kHz is sensible).



The speed of sound in air is around 330 m/s, so check your results roughly agree with this.

Measure the Speed of Water Ripples Using a Lamp

Using a signal generator attached to the dipper of a ripple tank, you can create water waves at a set frequency.

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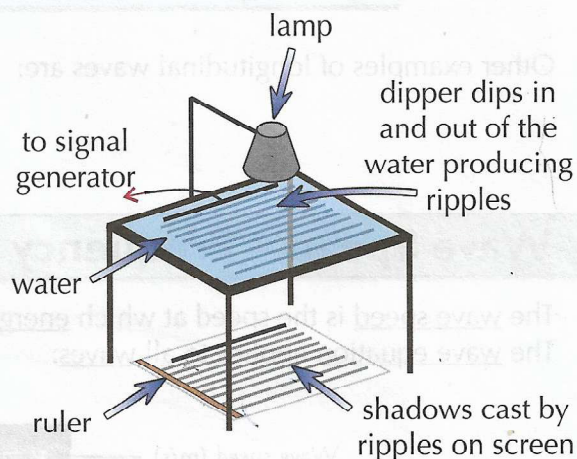
1) Dim the lights and turn on the lamp — you'll see a wave pattern made by the shadows of the wave crests on the screen below the tank.

2) The distance between each shadow line is equal to one wavelength (p.126). Measure the distance between shadow lines that are 10 wavelengths apart, then divide this distance by 10 to find the average wavelength. This is a suitable method for measuring small wavelengths.

3) If you're struggling to measure the distance, you could take a photo of the shadows and ruler, and find the wavelength from the photo instead.

4) Use $v = f\lambda$ to calculate the speed of the waves.

5) This set-up is suitable for investigating waves, because it allows you to measure the wavelength without disturbing the waves.



Experiments with Waves

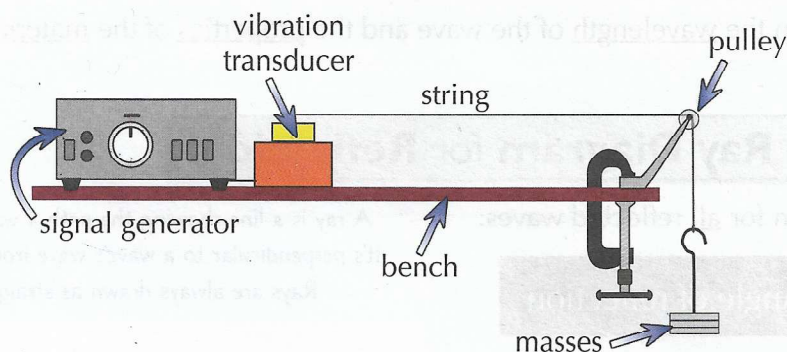
PRACTICAL

One more wave experiment coming up. This time, it's to do with waves on strings.

You can Use the **Wave Equation** for Waves on Strings

In this practical, you create a wave on a string. Again, you use a signal generator, but this time you attach it to a vibration transducer which converts the signals to vibrations.

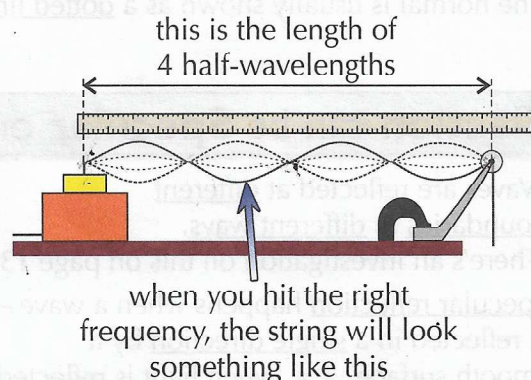
- 1) Set up the equipment shown below, then turn on the signal generator and vibration transducer. The string will start to vibrate.



This set-up is suitable for investigating waves on a string because it's easy to see and measure the wavelength (and frequency).

- 2) You can adjust the frequency setting on the signal generator to change the length of the wave created on the string. You should keep adjusting the frequency of the signal generator until there appears to be a clear wave on the string. This happens when a whole number of half-wavelengths fit exactly on the string (you want at least four or five half-wavelengths ideally). The frequency you need will depend on the length of string between the pulley and the transducer, and the masses you've used.

- 3) You need to measure the wavelength of the wave. The best way to do this accurately is to measure the length of all the half-wavelengths on the string in one go, then divide by the total number of half-wavelengths to get the mean half-wavelength (see p.8 for more on calculating the mean). You can then double this value to get a full wavelength.



- 4) The frequency of the wave is whatever the signal generator is set to.

- 5) You can find the speed of the wave using $v = f\lambda$.



Learn the methods for all these practicals...

These experiments seem complicated, but they all have a few things in common. First, you set the frequency on the signal generator, then find the length of the resulting wave (this tends to be the fiddly bit). You can then use the equation $v = f\lambda$ to find the wave speed. That's about it.

Reflection

You should be pretty familiar with the idea of reflection. Of course, there's a bit more to it than you'd think.

All Waves Can be Absorbed, Transmitted or Reflected

When waves arrive at a boundary between two different materials, three things can happen:

- 1) The waves are absorbed by the material the wave is trying to cross into — this transfers energy to the material's energy stores (this is how a microwave works, see page 138).
- 2) The waves are transmitted — the waves carry on travelling through the new material. This often leads to refraction (see the next page).
- 3) The waves are reflected — there's more on this below.

What actually happens depends on the wavelength of the wave and the properties of the materials involved.

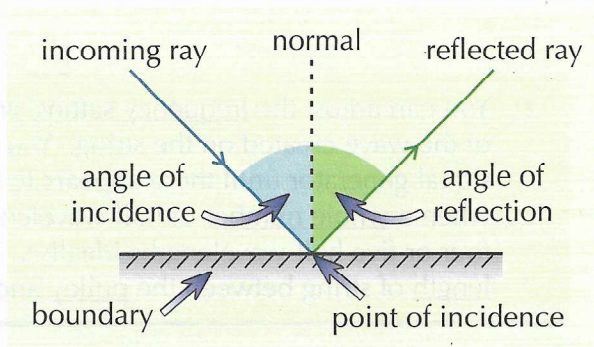
You Can Draw a Simple Ray Diagram for Reflection

- 1) There's one simple rule to learn for all reflected waves:

Angle of incidence = Angle of reflection

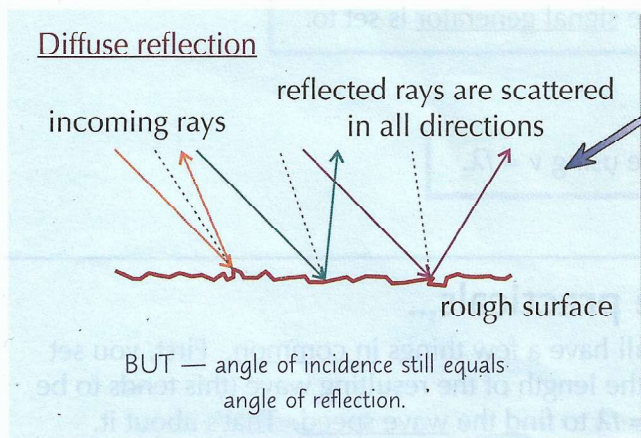
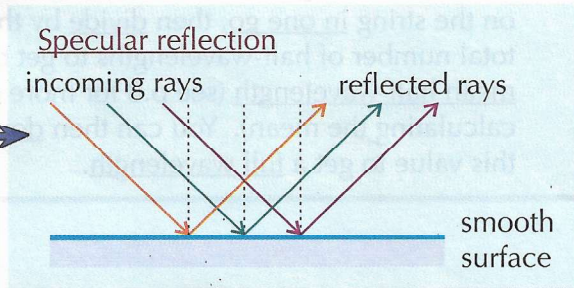
- 2) The angle of incidence is the angle between the incoming wave and the normal.
- 3) The angle of reflection is the angle between the reflected wave and the normal.
- 4) The normal is an imaginary line that's perpendicular (at right angles) to the surface at the point of incidence (the point where the wave hits the boundary).
- 5) The normal is usually shown as a dotted line.

A ray is a line showing the path a wave travels in. It's perpendicular to a wave's wave fronts (see p.131). Rays are always drawn as straight lines.



Reflection can be Specular or Diffuse

- 1) Waves are reflected at different boundaries in different ways. (There's an investigation on this on page 133.)
- 2) Specular reflection happens when a wave is reflected in a single direction by a smooth surface. E.g. when light is reflected by a mirror you get a nice clear reflection.



- 3) Diffuse reflection is when a wave is reflected by a rough surface (e.g. a piece of paper) and the reflected rays are scattered in lots of different directions.
- 4) This happens because the normal is different for each incoming ray, which means that the angle of incidence is different for each ray. The rule of angle of incidence = angle of reflection still applies.
- 5) When light is reflected by a rough surface, the surface appears matte (not shiny) and you don't get a clear reflection of objects.

Refraction

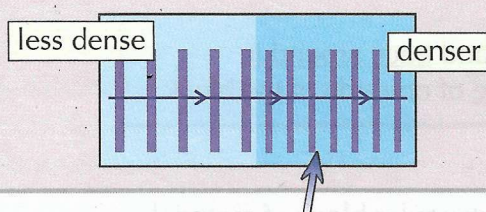
Refraction is when light waves are bent when they enter a new media (which is a posh word for material).

Refraction — Waves Changing Direction at a Boundary

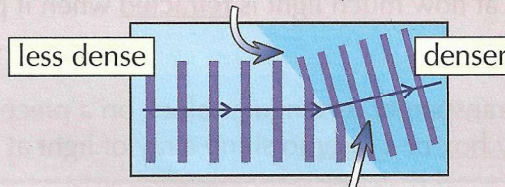
- 1) When a wave crosses a boundary between materials at an angle, it changes direction — it's refracted.
- 2) How much it's refracted by depends on how much the wave speeds up or slows down, which usually depends on the density of the two materials (usually the higher the density of a material, the slower a wave travels through it).
- 3) If a wave crosses a boundary and slows down it will bend towards the normal. If it crosses into a material and speeds up it will bend away from the normal.
- 4) The wavelength of a wave changes when it is refracted, but the frequency stays the same.
- 5) If the wave is travelling along the normal it will change speed, but it's NOT refracted.

See page 136 for more on different waves.

If a light wave hits the boundary 'face on', it carries on in the same direction.



But if a wave meets a different medium at an angle...



... the wave changes direction — it's been REFRACTED.

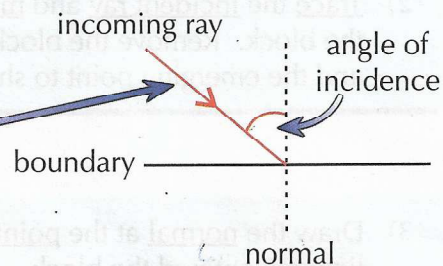
The wave fronts being closer together shows a change in wavelength (and so a change in velocity).

- 6) The optical density of a material is a measure of how quickly light can travel through it — the higher the optical density, the slower light waves travel through it.

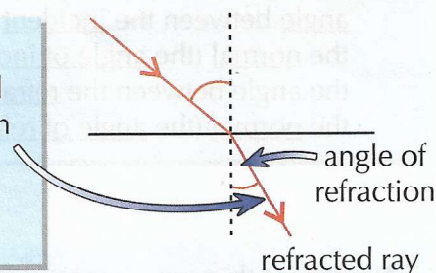
You can Construct a Ray Diagram to show Refraction

- 1) First, draw the boundary between your two materials and the normal (a line at 90° to the boundary).

- 2) Draw an incident ray that meets the normal at the boundary. The angle between the ray and the normal is the angle of incidence. (If you're given this angle, make sure to draw it carefully with a protractor.)



- 3) Now draw the refracted ray on the other side of the boundary. If the second material is optically denser than the first, the refracted ray bends towards the normal (like on the right). The angle between the refracted ray and the normal (the angle of refraction) is smaller than the angle of incidence. If the second material is less optically dense, the angle of refraction is larger than the angle of incidence.



Hitting a boundary at an angle leads to refraction...

If you can't remember which way a wave bends when it hits an optically denser material at an angle, imagine a skier skiing from some nice smooth snow onto some rough ground at an angle. The ski hitting the rough ground first slows down first, so they will swing towards that side.

PRACTICAL

Investigating Light

This is the first of two investigations in this topic that you'll come across. They're both to do with the behaviour of light. For both of them, you'll need a ruler, protractor and a nice sharp pencil.

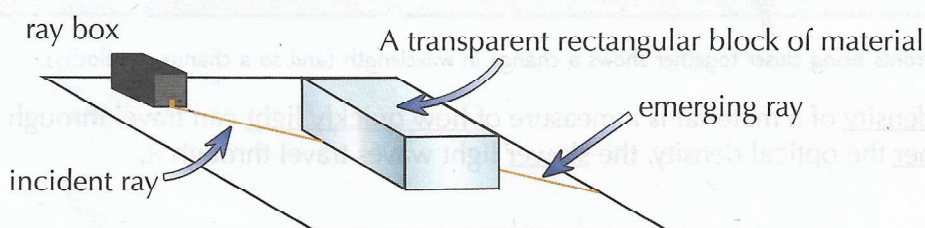
You Need to Do Light Experiments in a Dim Room

- 1) Both this experiment and the one on the next page use rays of light, so it's best to do these experiments in a dim room so you can clearly see paths of the rays of light.
- 2) They also both use either a ray box or a laser to produce thin rays of light. This is so you can trace the paths of the rays more accurately, meaning more exact angle measurements.

You Can Use Transparent Materials to Investigate Refraction

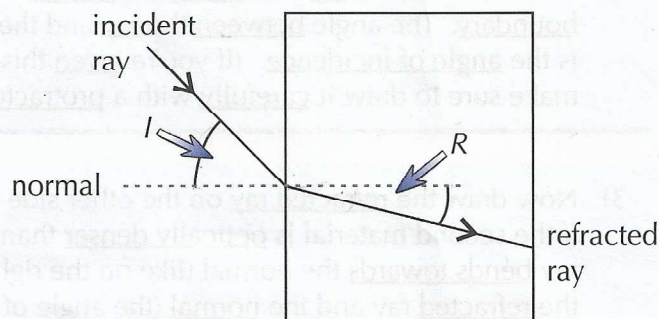
The boundaries between different substances refract light by different amounts. You can investigate this by looking at how much light is refracted when it passes from air into different materials.

- 1) Place a transparent rectangular block on a piece of paper and trace around it. Use a ray box or a laser to shine a ray of light at the middle of one side of the block.



- 2) Trace the incident ray and mark where the light ray emerges on the other side of the block. Remove the block and, with a straight line, join up the incident ray and the emerging point to show the path of the refracted ray through the block.

- 3) Draw the normal at the point where the light ray entered the block. Use a protractor to measure the angle between the incident ray and the normal (the angle of incidence, I) and the angle between the refracted ray and the normal (the angle of refraction, R).



- 4) Repeat this experiment using rectangular blocks made from different materials, keeping the incident angle the same throughout.

You should find that the angle of refraction changes for different materials — this difference is due to their different optical densities (see previous page).

Investigating Light

PRACTICAL

You've met reflection before — in daily life (every time you look in a mirror for example), and in more physics terms on page 130. Well, here's an investigation into reflection. It doesn't get much more fun than this.

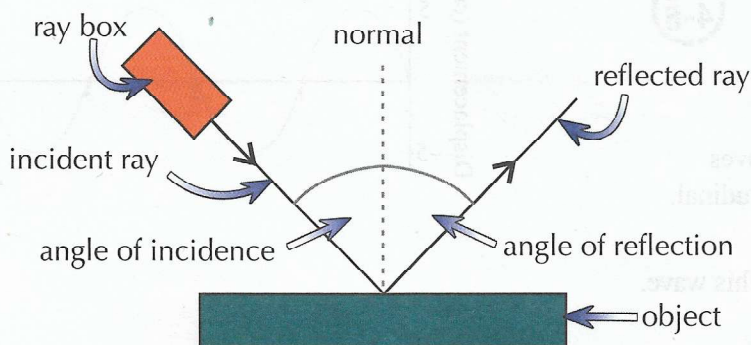
How Light Reflects Depends on the Smoothness of the Surface

This investigation allows you to compare how different surfaces reflect light, as well as confirming the rule for reflection given on page 130.

- 1) Take a piece of paper and draw a straight line across it. Place an object so one of its sides lines up with this line.

For a refresher on reflection, go back to page 130.

- 2) Shine a ray of light at the object's surface and trace the incoming and reflected light beams.



- 3) Draw the normal at the point where the ray hits the object. Use a protractor to measure the angle of incidence and the angle of reflection and record these values in a table. Also make a note of the width and brightness of the reflected light ray.

- 4) Repeat this experiment for a range of objects.

You should also see that smooth surfaces like mirrors give clear reflections (the reflected ray is as thin and bright as the incident ray). Rough surfaces like paper cause diffuse reflection (p.130) which causes the reflected beam to be wider and dimmer (or not observable at all). You should also find that:

The angle of incidence ALWAYS equals the angle of reflection.



Check your results are repeatable...

It's good to repeat this investigation, and the one on the previous page, just in case anything weird happened. You could have set up the experiment wrong, or you might just have read the wrong number off the protractor. Having repeat results will make these odd results easy to spot.